Bureau of Mineral Resources, Geology & Geophysics

R E C O R D

BMR Record 1992/30

Quaternary evolution, modern geological processes and potential effects of additional petroleum exploration activity on the Van Diemen Rise, Timor Sea (East Malita Graben Area) - Release 1 of 1992.

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Abstract

To meet the formal requirements for the collection, interpretation and analysis of environmental baseline data in Australia's offshore areas in which further petroleum exploration could take place, the modern geological processes, Quaternary evolution and environmental features of the potential release area(s) in the Van Diemen Rise (East Malita Graben, Timor Sea) which will be included in the first release of 1992 are described, analysed and interpreted.

The potential release area(s) overlie part of the Van Diemen Rise in the eastern part of the Timor Sea in the vicinity of Cootamundra and Evans Shoals. Sea bottom sediments in the region are dominantly calcareous sand grade and derived from the breakdown of skeletal material which has developed on an extensive number of banks and shoals which characterise this part of the continental shelf.

The sea bottom is also marked by a number of sinuous and narrow curvilinear channel like features which along with other geomorphic elements are attributed to the effects of subaerial exposure and weathering of the carbonate shelf sediment wedge during Quaternary lower sea level stages, as well as marine and coastal processes which occurred during sea level rise and marine inundation.

The Holocene rise in sea level has resulted in inundation of a large number of wave-cut scarps, channels and flat top banks, the latter of which became the focus of carbonate reef growth and hence a source of much of the sand-grade carbonate sediments evident on the sea floor.

Sea bottom sediments of the East Malita Graben area have been strongly affected by Holocene transgression. At approximately 18 000 years B.P. sea level was of the order of 120 metres below the present shoreline and much of the present shelf was subjected to subaerial exposure and erosion. A narrow shelf existed close to the edge of the continental shelf - shallow banks and shoals on the shelf were the focus of significant coral reef growth. Calcrete concretions formed on the exposed land surface under the influence of a low rainfall climate and a restricted estuarine embayment developed in the Bonaparte Depression.

Transgression rapidly flooded the shelf region and formed transgressive skeletal calcarenites with some calcareous concretion pellets. Around the banks and rises of

the shelf transgressive calacarenite has accumulated from coral debris. Landward of the present 50 metre depth contour present sedimentation is largely clastic and derived from the input of rivers which are most active in the monsoon (wet) season.

Foraminiferal calcarenites forming at present on the outer shelf are finer grained and contain more planktonic components the greater the water depth. Silty clays and molluscan debris are accumulating in the sheltered channels and the remains of large foraminifera and coralline algae are accumulating on the shallow banks and rises. A similar assemblage dominated by *Halimedia* is growing on the very shallow shelf edge banks.

Major ecological features of the current coastal zone adjacent to the potential release area(s) include mangrove, seagrass and reef communities. Human activities which can adversely affect each of these elements include such effects as increased nutrient levels from runoff and other discharges associated with human settlements and activities.

Petroleum exploration activity, in the form of seismic surveying and possibly drilling, are the main activities likely to be undertaken in the potential release areas. The transitory nature of these activities and their variable location would in normal circumstances result in no long-term visible impact on environmental conditions and at worst only very minor short-term localised disturbance. At the completion of exploration work the only visible signs of drilling would be the presence of rock fragments on the sea bottom and normal current and tidal action would disperse these within a short period. The impact of the installation of production facilities would require more specific examination beyond the scope of this analysis.

Introduction

Petroleum operations in Australia, beyond coastal waters, are governed by Commonwealth legislation and this, in part, is administered jointly with the States and Northern Territory. The twelve million or more square kilometres of ocean waters surrounding the continent are rich in natural living resources as well as overlying sedimentary basins with proven oil and gas potential.

The recent releases of vacant petroleum exploration areas for application under Commonwealth legislation (Release of Offshore Petroleum Exploration Areas, Release No 1 1992) have been accompanied by a list of special conditions. These special conditions require that successful exploration groups applying for the right to drill exploration wells during the course of a permit work program will have to supply to the Commonwealth, firstly, a description of the environment, both within the permit and adjacent to it, which is likely to be affected by drilling and production - where there is written material already available this has to be included. Secondly, a description of the potential impact of drilling and production on the environment, a description of safeguards and standards for the protection of the environment intended to be adopted and applied in connection with the drilling of the well and future production.

In response to the demand for environmental baseline data, some of which has been collected by the petroleum exploration industry during the course of its exploration and production activities, the Bureau of Mineral Resources, Geology and Geophysics (BMR) has acquired and is interpreting a wide variety of data relating to baseline environmental conditions. Major regional surveys of marine geology of Australia's continental margins provide a unique insight into the nature of Australia's marine environment, its diversity and variability. Such surveys have been undertaken for the past thirty years by BMR.

The potential impact of petroleum exploration and production activity on Australia's marine environment has over a 30 year period of major petroleum production proved to be negligible with a total of 350 barrels of oil being accidently released during the course of producing two and a half billion barrels of oil (Griffiths, 1991). Maritime shipping into and out of Australian ports has been responsible for the accidental release of most oil into the marine environment.

The specific requirements for descriptions of the environment surrounding sites on which petroleum exploration drilling is proposed has formalised a process the industry has been undertaking for a considerable period of time. Site surveys, water temperature, current, wave, wind and tide patterns, and other oceanographic data have been evaluated as part of the process of petroleum exploration and development (Holloway, 1988). The special conditions which now require formal documentation of such information in applications to drill exploration wells has resulted in the research, interpretation and analysis of such information in the following form by BMR for use by government, the industry and the public.

The Van Diemen Rise (East Malita Graben Area) is likely to be included in Release 1 of 1992 and it overlies the Australian continental shelf between 9-30.0 and 10-0.0 south and 128-15.0 and 129-45.0 east (Figure 1). Water depths in the area increase to the north and northeast from less than 100 m to over 400 m. The central and southern parts of the area (Figure 1) comprises a complex series of relatively shallow flat top banks. Cutting through the banks are a series of sinuous channels and terraces which are the result of regional erosion (Figure 2). Cross correlation of such features allows for up to four base levels at which erosion and physical weathering processes have been active for short but significant periods.

Although no specific means of correlating the offshore terraces and bank tops with the onshore erosion surfaces described by van Andel & Veevers (1967) are available, the general form of the coastal plain surface they describe is similar to Surface I outlined in their publication and shown in Figure 2 (Cross section AA') for the banks in the southern part of the vacant area. This is younger than the onshore Wave Hill surface which has been identified broadly as Miocene in age. An extensive unconformity (S3) Veevers (1971) identified in seismic records of the Sahul Shelf could correlate with the Wave Hill surface. In contrast, the Coastal Plain surface has several stages onshore and these appear compatible with the offshore Pleistocene stages shown in Figure 2. Two unconformities identified by Veevers (1971) on the Sahul Shelf (S1 & S2) are Late Pliocene and Pleistocene and may correlate with development of an older part of the coastal plain surface. These surfaces have had a major influence on the form of the sea floor in and around the vacant area and the lithology and biofacies currently evident in the region.

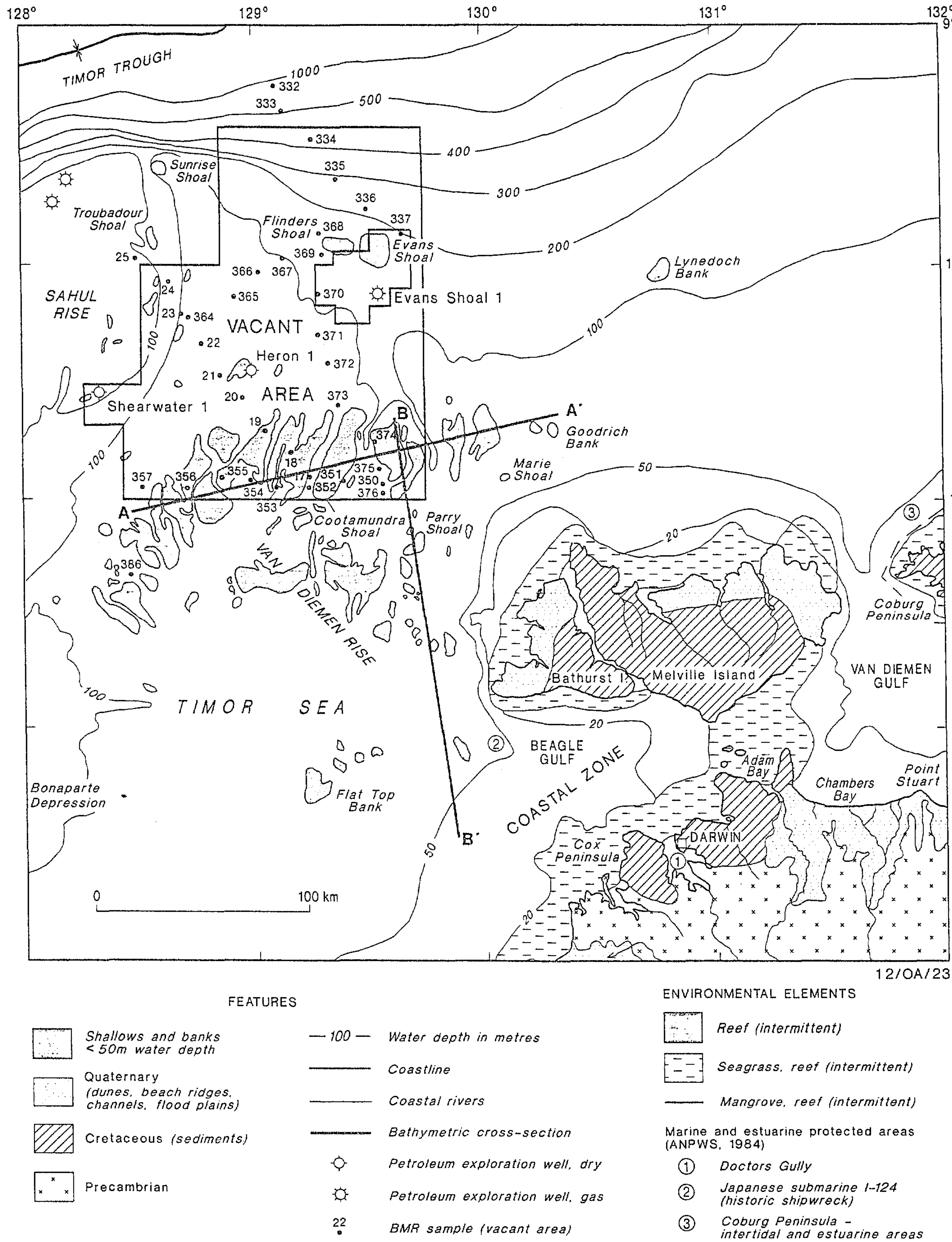

Figure 1 Location map, bathymetry and simplified geology/geomorphology.

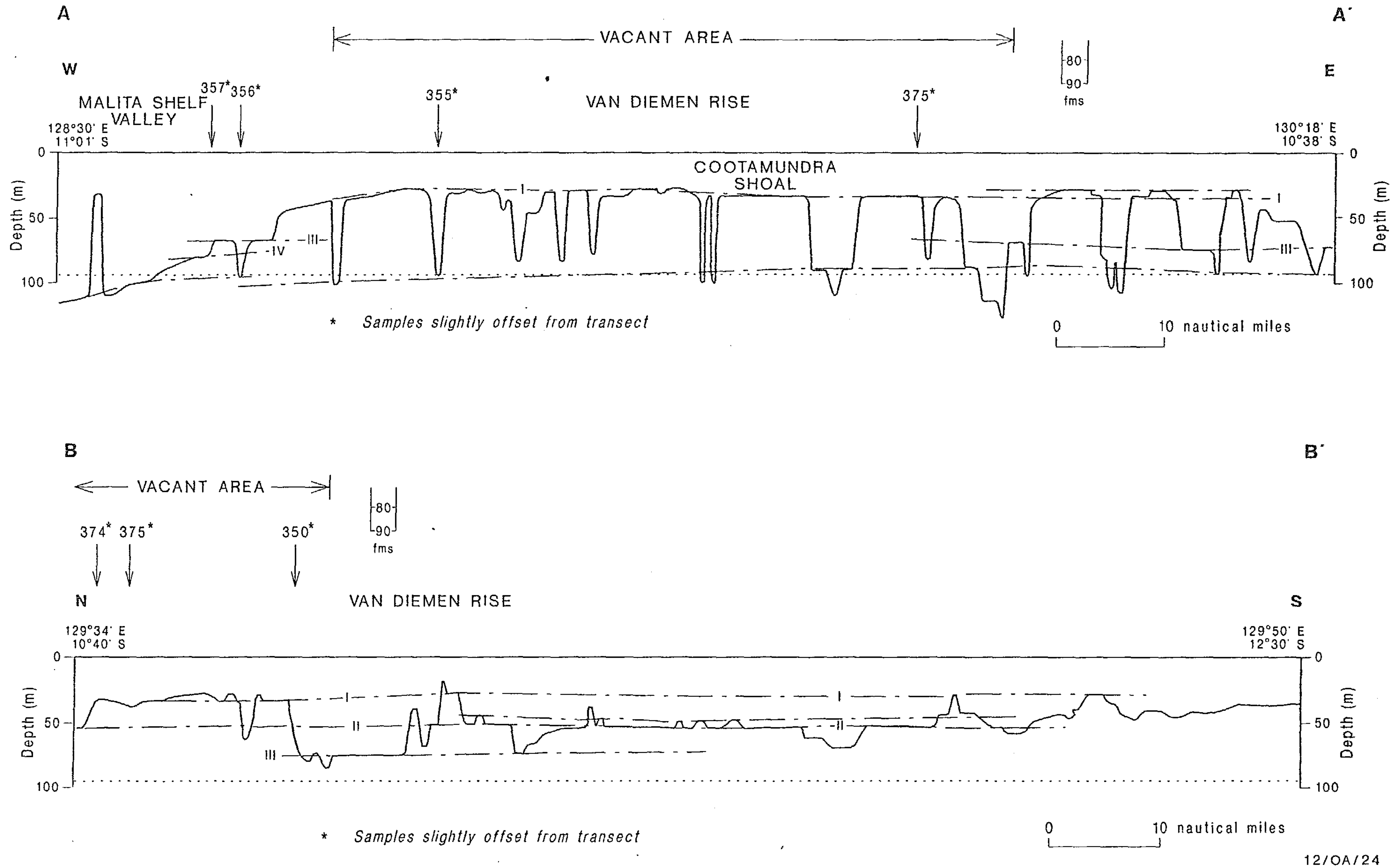

Figure 2. Cross sections of sea bottom topography. Vertical exaggeration is x 200.

Northern Territory coastal zone

Coastal areas of the Northern Territory, landwards of the waters covering the vacant area, are noted for their diverse and significant physical and biological resources. Those resources accordingly represent considerable economic, recreational and conservation values (NTDME, 1991).

For definition purposes only the 'coastal area' exists seawards to 25 nautical miles off-shore or the 50 m depth contour, whatever is greater from shore, and extends onshore to include all landforms which are subject to coastal processes, including mobile sand dunes and chenier beach ridges (NTDME, 1991) (Figure 1).

Three basic divisions of the coastal area are readily made, based on the dominant sedimentological processes as well as the biofauna inhabiting each major geographical element (Figure 1).

The first division is the intertidal zone which includes the areas between high and low tides levels. Elements such as mangroves, salt marshes, some seagrass beds, mudflats, sand flats, with lesser sandy beaches and dune systems may be present (NTDME, 1991).

Generally landwards of the intertidal areas are such features as dunes and chenier beach-ridges, as well as low-lying areas which become water-logged during the monsoon season including, paperbark swamps and monsoonal vine thickets. Such areas are the supratidal zone and comprise a buffer between the intertidal zone and non-marine environments per se.

The final element identified in the NTDME (1991) coastal area description is that of subtidal zone - marine or estuarine areas below low tide level. Elements in this group are major tidally-influenced channels, coastal lagoons, coral reefs, seagrass banks and shoals, as well as marine shelf areas.

A variety of cultural, social, biological, geological and geographical values are attributed to many of the coastal features of the Northern Territory (NTDME, 1991). Some are considered likely to be sensitive to the impact of activities associated with exploration and development work where that activity includes dredging, drilling and seismic exploration using explosive sources.

Features which have been identified as being likely to be adversely affected by such activities include marine and estuarine protected areas, sacred sites, occupational reserves, fisheries reserves and undeclared areas. Other undeclared areas such as seagrass, mangroves, turtle or bird breeding areas, shipwrecks, recreational sites and potential aquaculture development sites are also the subject of considerable interest.

No declared protected areas are listed by the Australian National Parks and Wildlife Service (ANPWS, 1984) in the vacant East Malita Graben area.

Climate

All of northern Australia including the coastal regions closest to the vacant area are subject to a monsoon climate, with a wet season during the northwest monsoon (summer) and a dry season during the southeast monsoon (winter), from May to October. Rainfall varies from 720 mm to 1920 mm (30 to 80 inches) per year. Mean temperatures in the wet season are in the high 20 to 30's (degrees Celsius) with high humidity, down to 18 to 20 degrees Celsius in the dry season (low humidity). Thunderstorms occur on average 85 days per year in Darwin (summer). The mean average evaporation rate is approximately twice the average annual rainfall (van Andel & Veevers, 1967).

The seasonality in temperature and wind regimes has a significant effect on the salinity levels in nearshore areas and water temperature. Nearshore waters can vary in temperature (by 10 degrees Celsius) and salinity (Poiner & others, 1987) but this variation is less marked in offshore areas. Much of the nearshore variation is related to the volume (and sediment load) of runoff from coastal river systems. The northern Arnhem Land coast is less affected by runoff than the Joseph Bonaparte, Van Diemen and Gulf of Carpentaria.

The Arafura and Timor Sea areas are noted for a mean annual precipitation of 900 mm and a mean annual evaporation of 1716 mm . A southeast trade wind blows from May to October in the dry period, and from the northwest from November to April (wet season). Tropical cyclones lasting from 12 to 24 hours occur in the latter period. Wind velocities of 50 to over 90 knots, even as high as 140 knots are developed during cyclonic conditions. Squalls in the dry season rarely last longer than 3 hours and develop winds of 30 to 100 knots (van Andel & Veevers, 1967).

The southeast trade winds can generate moderate to rough seas, the main swell being from the southeast. During much of the monsoon season seas are calm and smooth except for the disturbance caused by tropical cyclones. Swells developed during cyclones come from the southwest, west and northwest.

Geomorphology

The East Malita Graben area overlies much of the northern extent of the Van Diemen Rise - a bathymetric feature comprising a complex array of relatively shallow banks cut by numerous narrow sinuous channels, some of which are bordered by terraces of varying inferred ages and are the result of regional erosion (Figure 2). Cross correlation of such features allows for up to four base levels at which erosion and physical weathering processes have been active for short but significant periods.

Although there are no specific means of correlating the offshore terraces and bank tops with the onshore erosion surfaces described by van Andel & Veevers (1967), the general form of the coastal plain surface they describe is similar to Surface I outlined in their publication and shown in Figure 2 (Cross section AA') for the banks in the southern part of the vacant area. This is younger than the onshore Wave Hill surface which has been identified broadly as Miocene in age. An extensive unconformity (S3) Veevers (1971) in seismic records of the Sahul Shelf could correlate with the Wave Hill surface. In contrast, the Coastal Plain surface has several stages identified onshore and these appear compatible with the offshore Pleistocene stages shown in Figure 2. Two unconformities identified by Veevers(1971) on the Sahul Shelf (S1 & S2) are Late Pliocene and Pleistocene and may correlate with development of an older part of the coastal plain surface. These surfaces have had a major influence on the form of the sea floor in and around the vacant area and the lithology and biofacies currently evident in the region.

Quaternary history

In the Tertiary period much of the present coastline of northern Australia, including the marine shelf underlying the vacant area was elevated above sea level and subjected to subaerial erosion (Jongsma, 1974; Hughes, 1978). During the Pleistocene several changes in sea level occurred and were followed by a final Holocene transgression. These processes were identified by Jongsma (1974) and are apparently reflected in the development of submarine terraces.

Jongsma (1974) identifies a terrace at 200 metres subsea which he suggests formed 170 000 years B.P. (possibly Riss Glacial Stage). He also identifies a transgression before 30 000 B.P., a lowering of sea level after 30 000 B.P. which formed terraces at -180 metres and -120 metres subsea (Wurm Glacial Stage), and a transgression from about -120 m subsea at 15 000 years B.P. The latter terrace was formed before the Holocene transgression which resulted in the inundation of river systems and the formation of chains of islands and straits typical of the present coastline.

Higher than present sea levels or local tectonic uplift are responsible for the development of chenier beach ridges and strandline features at higher levels and up to 3 km inland of the present coastline (Hughes, 1978).

More detailed investigation by Lees & others (1990) and dating of such dune systems indicates that they developed in an episodic fashion - the first period of dune and chenier building falls between 2 600 and 1 800 years B.P., a second period falls between 8 500 and 7 000 years B.P. and a third between 81 000 and 171 000 years B.P. The last of these is similar to the oldest terrace identified offshore by Jongsma (1974).

Each of these periods of dune building and development identified by Lees & others (1990) coincides with drier climatic change, higher evaporation and lower precipitation. Reduced vegetation cover resulting from the drier climate and seasonally persistent winds have resulted in greater dune mobility. Rising sea levels further contribute by eroding foredunes initiating blowouts and the development of transgressive dune sequences (Lees & others, 1990).

Stabilisation of dune systems by vegetation halts the process and this usually coincides with periods of increased rainfall. Past studies have highlighted the additional contribution of local sediment budgets, glacial low sea level stands, marine transgressions, cycles of storms and anthropogenic disturbances as the source(s) of processes leading to dune formation and emplacement (Lees & others, 1990).

A specific examination of the strandline units at Point Stuart, approximately 15 km east of the mouth of the Mary River, on the coast of Van Diemens Gulf east of Darwin by Lees (1987) has identified at least five chenier ridges which have formed in the last 1270 years. Major storms over an 80 to 200 year frequency appear to have built the five ridges closest to the coast. A further five ridges landwards of this set have a much lower proportion of carbonate and shelly material and differences between the two sets are explained by a major change in the pattern of sediment supply (Lees, 1987). The switching of the Adelaide River system from Chambers Bay to Adam Bay and the abandonment of a single channel for the Mary River to several discharge channels may be the cause of the differences between the two sets of chenier systems.

The beach ridges at Point Stuart and others around the coastal fringes of northern Australia are formed by storm waves where wave base reaches deeper and further offshore than normal. Wave-winnowing can excavate shelly material and remove fine grained sediments, allowing coarse-grained sediments and shell debris to accumulate on the strandline or at storm-surge level landwards of the normal strandline.

Recent sedimentation

Each of the major coastal features identified above is noted for the development of a suite of sediment types such as fluvial channel and floodplain sequences landwards of the coastal system. These comprise silt, fine sand, mud, minor gravel and alluvium up to a total of 5 metres in thickness in meander channels, swamp depressions and even cut-off meanders. Towards the hinterland and in between such units are red sandy and mottled grey to yellow sandy soils up to 10 metres thick which form in colluvial and eluvial environments (Hughes, 1978). The latter are generally developed as a result of the erosion and dissection of Tertiary and possibly older consolidated sequences.

In coastal and offshore areas littoral, aeolian, intertidal deltaic and estuarine sand, shell and coral debris, organic rich mud and silt are being deposited in sequences up to 20 metres thick. Beach and littoral strandline sands are evident on present coastlines and as low vegetated ridges. Along some shoreline and other areas Pleistocene coquina, calcarenite and conglomerate have formed in sequences up to 8 metres thick (Hughes, 1978). The extensive estuarine systems are evident at the mouths of major river systems developed where marine inundation drowned existing river valleys.

The modern sediments of the Timor and Arafura Seas are most extensive in the nearshore areas of less than 50 metres in water depth. Within these areas sediment distribution is irregular, being controlled by proximity to sediment sources and the degree of exposure to tidal and wind generated activity. The current pattern of modern sedimentation and older Quaternary units is thought to be the combined effect of sea-level fluctuations, relict deposits and subaerial, fluvial, lacustrine and marine conditions (Jones, 1987). During the past 6000 years sea level is thought to have been relatively stable at or near its present level (Thom & Chappell, 1978).

Fluvial sediments are the major input into the Timor and Arafura Seas from the coastline and hinterland, more so where major river systems empty into sheltered bays and estuaries such as those in the Joseph Bonaparte and Van Diemens Gulfs. Where wind and wave energy are sufficient, fine-grained terrigenous sediments transported down river systems in the wet season are prevented from being deposited in nearshore areas and are deposited offshore over older late Pleistocene continental and marine sequences.

Carbonate comprises much of the offshore sediments deposited in the vacant area at present but is mixed with a significant amount of fine clastic material to form calacarenite with some silty calcilutite (Figure 3). The sequence is part of a broad suite of calcarenite and calcilutite which is a significant feature of the outer continental shelf in the Timor Sea and parts of the Arafura Sea. The calcarenite is derived from the breakdown of skeletal and algal carbonate material deposited on the shallower and more turbulent banks and rises of the outer shelf. Although such areas are now covered by water depths of the order of 50 metres the latter feature is due to a Holocene rise in sea level and or additional local subsidence. Prior to the sea level rise, the shelf area was much narrower and the banks and shoals of the outer shelf were part of an active reef and carbonate bank system which fringed the shelf edge.

Some fine clastic (clay grade) material is deposited from suspension as a result of plumes derived from major river systems which are most active in the monsoon wet season. Analyses of the clay fraction in sediments of the region in which the vacant area is located are reported by van Andel & Veevers (1967); and they indicate that the clay fraction is predominantly kaolinite derived from an onshore deeply weathered lateritic hinterland. Organic carbon content in the clay fraction in the region of the vacant area is between 0.75 and 1.00% and may reflect the input from both terrestrial and marine sources. Heavy minerals present in the minor sand

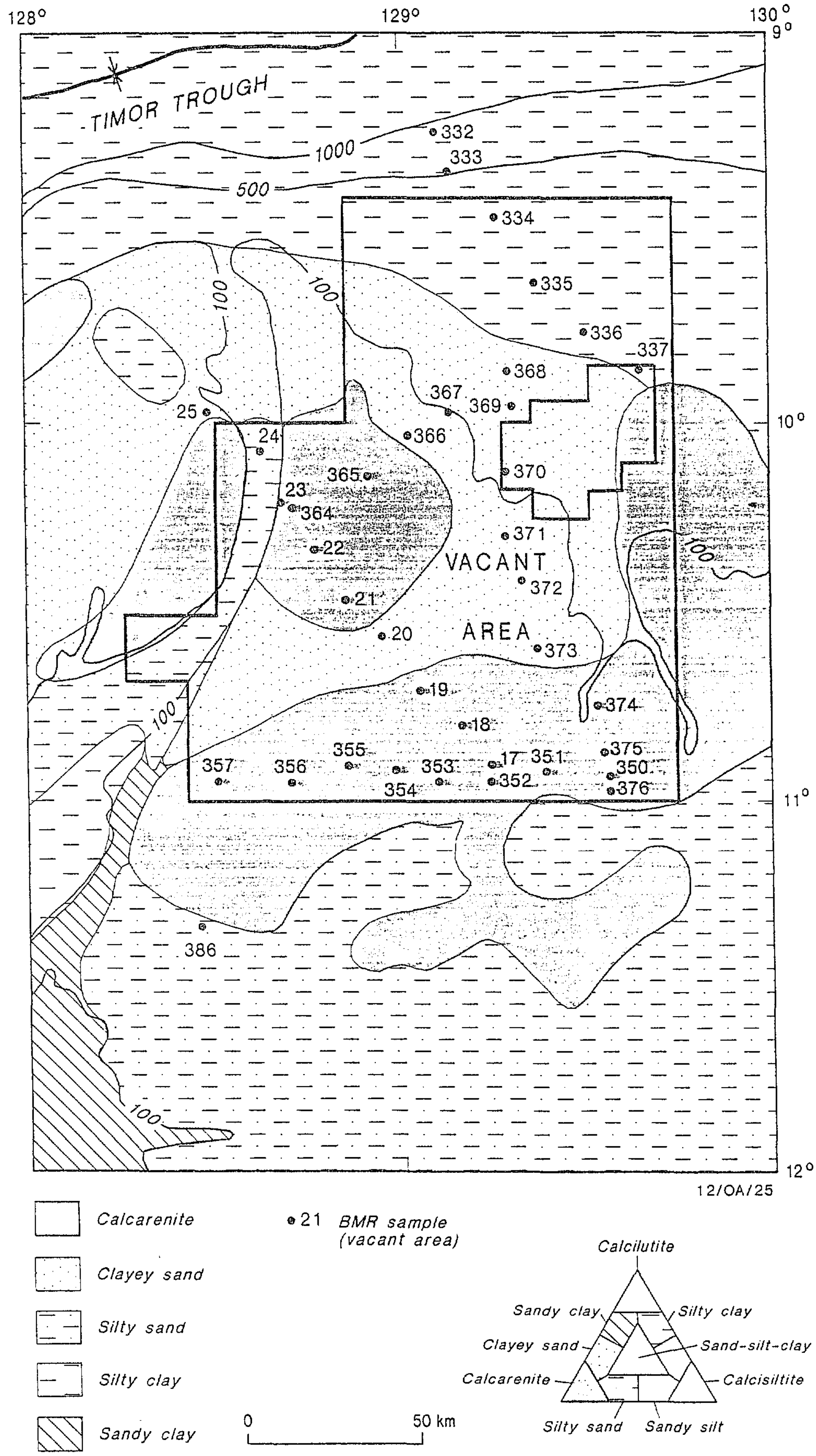

Figure 3. Lithofacies map

fraction of sediments in the region are largely tourmaline and zircon derived from a deeply weathered sedimentary terrain onshore (van Andel & Veevers, 1967).

The coarse fraction of recent sediments deposited in the vacant area is largely skeletal material derived from organisms and processes developed in situ, except for remnant features derived from older sequences (van Andel & Veevers, 1967). Smaller foraminifera, algal and coral colonies provide a major source for the remainder of the skeletal remains on the shallowest banks on the Van Diemen Rise and Evans Shoal.

Side scan sonar records obtained prior to drilling of the Evans Shoal No. 1 well (WMC, 1988) indicate that in the vicinity of the vacant area the sea bottom is of the order of 102 to 118 metres deep and comprises unconsolidated carbonate sands. The topography of the sea bottom proximal to the well site was notable in that circular depressions of the order of 10 to 30 metres diameter and 1.0 to 2.0 metres deep are readily evident. In some cases the edge of these features exhibit a raised outer lip. The interpretation of their origin is subject to conjecture because of the lack of specific information. Fluid release in the form of biogenetic or thermogenetic gas are possible reasons for the development of such features, as is subsurface dewatering of semi-consolidated sediments.

Lithofacies

Sampling from the vacant area was undertaken by van Andel & Veevers (1967) as part of a major regional study of the Timor Sea (Figure 3). The results from approximately 35 sea bottom samples collected and analysed from within and adjacent to the vacant area are graphically displayed in Figure 3.

While the sea bottom sediments of the vacant area are predominantly of sand grade material much of this is actually derived from skeletal material. Calcarenites and clayey and silty calcarenites cover the banks, rises and channels of most of the vacant area. The coarsest calcarenites are found on the tops of banks and shelf edge banks. Beyond shelf edge banks such as Evans Shoal towards the Timor Trough clay and silt grade material is dominant and is derived from planktonic foraminifera.

Some silty sand is also present on the extensive number of banks landward of (shallower than) the 200 metre depth contour.

Biofacies

Samples of sea bottom sediments were subjected to detailed analysis by van Andel & Veevers (1967). The coarse fraction of all samples in the Timor Sea region, including those collected in and around the vacant area, were examined and classified into major components (particles coarser than 0.062 mm). As most of such components are skeletal material they reflect the remnants of living organisms. Their distribution may reflect the impact of transporting agents as well as the living habitats of the organisms. The major components identified by van Andel & Veevers (1967) are as follows (Figures 4 & 5).

Halimedia were tabulated separately, all other calcareous algae such as *Lithothamnium* and *Amphipora* are combined. Larger foraminifera include *Marginopora*, *Heterostegina*, *Amphistogina*, *Cycloclypeus*, *Aveolinella*, *Calcarina*, *Sorites*, Peneroplids, and large Miliolids (van Andel & Veevers,1967). Smaller foraminifera comprise the remainder. Minor components such as ostracods, pteropods and crustaceans were not significant. Lithoclasts comprise calcareous and terrigenous fragments cemented by calcite.

Using the end members identified in the analysis of all samples in the Timor Sea, including those in the vacant area, van Andel & Veevers (1967) used a correlation coefficient to measure positive and negative covariance between the various components (Figure 4). The essential groupings reflect those components which are likely to be found in similar habitats and locations: corals/bryozoans, algae/forams, molluscs/echinoids. In additions it also shows those which are not cohabitants eg. small foraminifera and glauconite/terrigenous versus the remainder. Only the groups with a positive correlation of greater than 0.01 are statistically significant.

The small foraminifera are a regional 'background' biofacies (Figure 5) on which others are superimposed. With increasing distance from shore there is an increase in the proportion of planktonic forms in this group and it is dominant in the deep waters of the Timor Trough. The molluscan group is dominant in and around the Bonaparte Depression which was the location of a major Quaternary marine estuarine embayment.

The coral/bryozoan group is present on the banks and rises of the western Sahul Rise (Figure 5) and Van Diemen Rise although it is limited to the seaward edge of the major groups of banks in the vacant area. The algal/foraminifera (large) group is

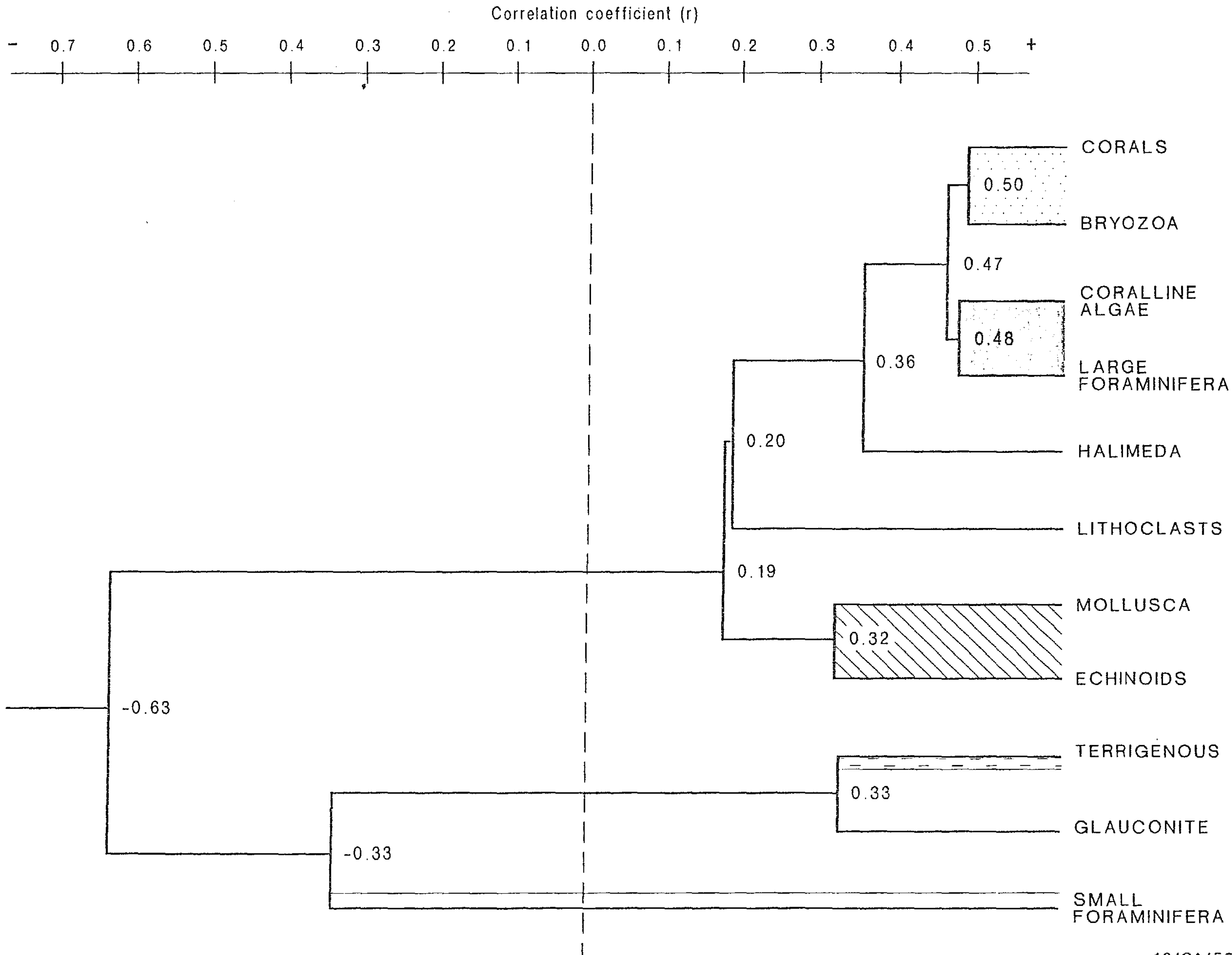

Figure 4. Dendrograph of biofacies associations

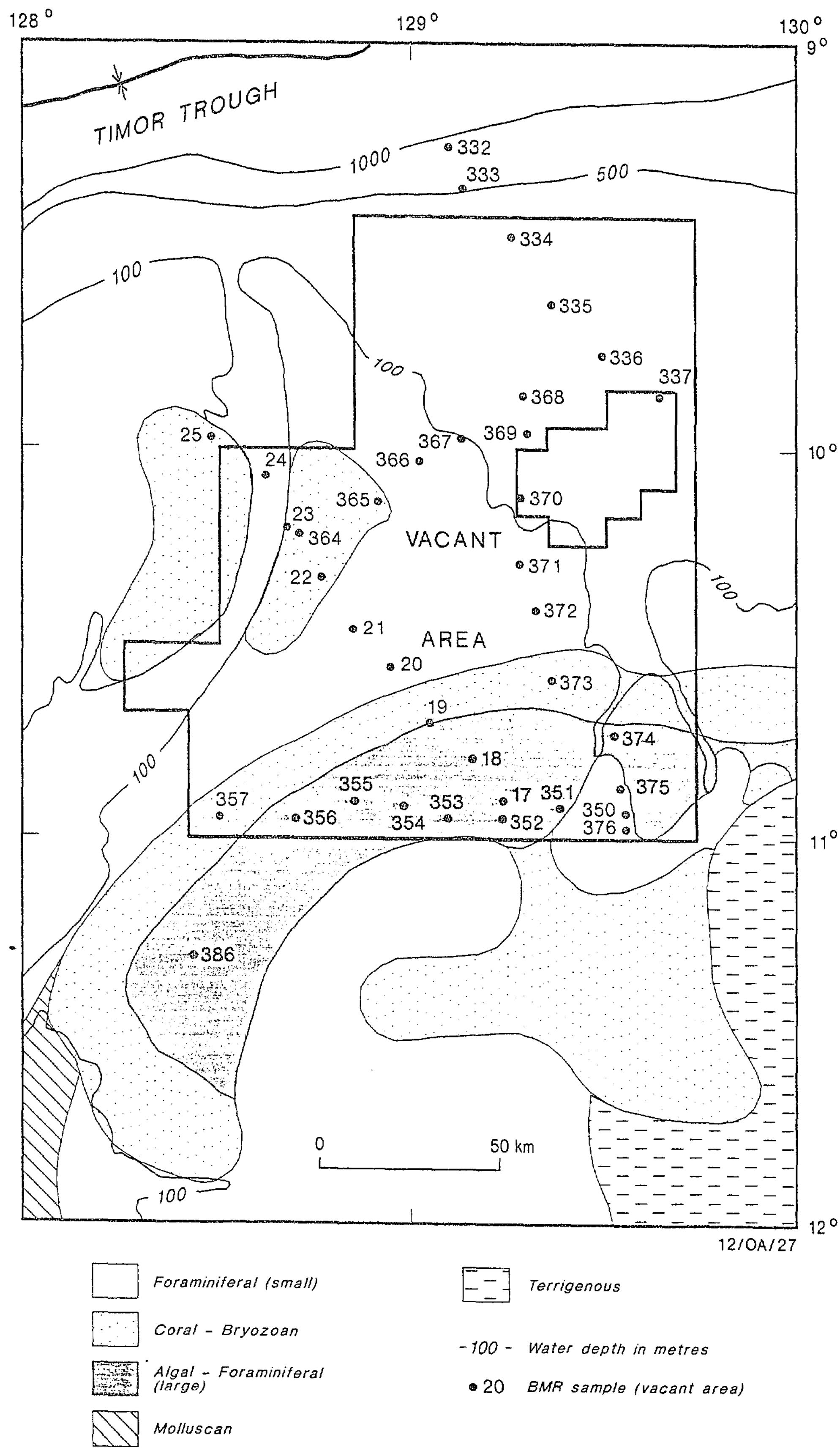

Figure 5. Biofacies map

present on the shallowest and broadest banks of the Van Diemen Rise. The terrigenous end member is limited to an area closest to the coast and it has developed as a result of the input of clastic material from major river systems during the wet season.

In additional to the biofacies evident on the seafloor other major ecological associations are developed within the terrigenous biofacies including seagrasses and mangroves.

Major ecological features

Mangrove

These are essentially marine tidal forests and are adapted to colonising loose wet soil types which are subject to periodic tidal submergence. On the Northern Territory coastline conditions favourable to their development are widespread, particularly around coastlines in bays, tidal channels and estuaries. The overall control on the occurrence of mangrove forests is the minimum air temperature, although they are known to range into temperate parts of the Australian coastline (Hatcher & others, 1989). Locally such conditions as soil salinity, frequency of tidal inundation, sedimentation, rainfall variation and frequency of tropical cyclones all contribute to the richness of tree species in mangroves (Smith & Duke, 1987). There is some debate over whether mangroves are the cause of sediment aggradation and accumulation or the opportunistic consequence of existing sedimentation processes. They are generally regarded as the means of stabilising sediments deposited by the prevailing physical forces rather than the cause of sedimentation.

Optimal conditions for mangrove development are generally present in brackish water areas. The theory that mangroves are important sources of outwelled dissolved nutrients has been challenged by Boto & Wellington (1988) who suggest that no net annual exchange of organic or inorganic nutrients occur in mangroves and that they require a significant import of dissolved phosphorus for growth. They are however important areas for the development of juvenile fish and prawns (*Penaeus merguiensis* in particular) (Staples & others, 1985). Mangroves in Northern Australia have been demonstrated to contain a order of magnitude greater number of juvenile fish and prawn species than adjacent seagrass, bay and estuarine areas (Robertson & Duke, 1987).

Major causes of disturbance to mangroves from human activities are generally those which result in reclamation of intertidal areas for industrial or other uses. The presence of iron pyrite (FeS_2) in the anaerobic subsoil of such areas can render them unsuitable for use in agriculture and aquaculture (Hatcher & others, 1989). There is a very close correlation between the areal extent of mangroves on the Carpentaria coast of the Northern Territory and the size of commercial prawn catches in adjacent coastal waters (Kirkwood & Somers, 1984).

While spillages of crude oil are very rare and mainly occur as a consequence of maritime transportation mishaps they can have an significant impact - the effects can be cumulative for mangroves exposed to the side effects of high-density maritime traffic. The presence of 2.4 per cent crude oil by weight in the sediments of mangroves has been shown to be sufficient to prove fatal in 2 months resulting from the interruption of water supply to the leaves (Allaway, 1987). The speed of recovery is potentially related to the period required to degrade the crude oil.

Seagrass

Seagrass communities develop below the low tide zone and in estuaries, bays and the open ocean into water depths of up to 30 metres. Water clarity is the factor which controls the depths of seagrass development. In turbid water they grow in very shallow depths due to a low level of light penetration. Their significant effect on the substrate is in binding sediment particles together by means of a fine mat of roots thus stabilising it. The effect of widely vegetated substrates is that they can reduce the height of storm surges and provide a physical baffle against tidal and current flows (Hatcher & others, 1989). The latter development can encourage the settlement of benthic larvae in areas of sheltered water and thus significantly increase local species diversity. Seagrass communities are known to be present on the coastal fringes of the Timor Sea, Bathurst and Melville Islands, the coastline of the Cox Peninsula and the western part of the Gulf of Carpentaria (Figure 1).

Seagrass communities are also important nursery grounds for juvenile tiger and endeavour prawns which are of major importance in the prawn catch from northern Australia (Poiner & others, 1987). The seagrass communities of the Northern Territory coastline contain similar species to those in the Gulf of Carpentaria and inhabit intertidal to shallow subtidal areas. Species of *Cymodocea*, *Halodule*, *Enhalus*, *Thalassia*, *Syringodidium* and *Halophila* are most commonly present (Poiner & others, 1987). The seagrass assemblages evidently occur in both depth-limited associations along open coastlines as well as mixed-species associations from the intertidal zone. The depth-limited communities tend to be dominated by a single species such as *Syrinodium* sp. , *Thalassia testudium* and or *Cyodocea serrulata* (Poiner & others, 1987) .

On open coastline areas monospecific stands of *Halophila ovalis* and *H. uninervis* dominate the intertidal zone, whereas *C. serulata* and *S. isoetifolium* are the major species in the subtidal areas (Poiner, & others, 1987).

The western part of the Gulf of Carpentaria has been closely investigated for the interaction between prawn populations and seagrass communities (Poiner & others, 1987) and the results appear to be applicable to other parts of the Northern Territory coastline. Of the four types of seagrass community in reef-flat, open coastline, sheltered embayment and river mouth areas, juvenile prawns were least well represented in the river mouth area, were most prevalent in the sheltered embayment and of intermediate numbers in the reef-flat and open coastline areas (Poiner & others, 1987).

Human activities which can most seriously impact on seagrass communities are the dredging and infilling habitat areas. Significant side effects can also develop without direct disturbance because of turbidity or the resuspension of unconsolidated sediments (Hatcher & others, 1989). Increased nutrient levels in runoff from the landsurface can also lead to widespread mortality and habitat loss. Even with only mild disturbance habitat changes can occur and be sufficient to cause a turnover from the more diverse subtidal species assemblage to the hardier intertidal forms.

Reef

In the Arafura and Timor Seas reefs are evident on shallow banks and the outer shelf edge (van Andel & Veevers, 1967). Coralline algae are the dominant component of these assemblages along with larger formanifera. The dominant coral component are *Halimedia* and the algae *Lithothamnium.*

The dominant feature of both the Timor and Arafura Sea reefs is the remnant nature of reef-related carbonate formation on the outer shelf edge, the site of significant reef-building activity during the Quaternary (lower sea level). As sea level rose during the last 20 000 years B.P. reef-like growth on the outer shelf has generally been unable to keep pace with the rise in sea level, and the focus of reef growth spread landwards onto banks and shoals back towards the present coastline as the influx of clastic material in these areas decreased with greater marine inundation.

Reef development is also patchy because of the additional impact regional subsidence has had causing inundation and the submergence of most sites on the outer shelf edge. Despite the presence of mangrove, seagrass and reef communities in coastal zone and outer shelf areas of the Arafura and Timor Seas, most of the seabottom on the extensive marine shelf areas consists of unconsolidated sediment inhabited by a limited epifauna and infauna which have been classified into the biofacies shown in Figure 5.

Other elements

Northern Territory coastal waters also support significant commercial and recreational fishing activities including pearl, prawn, fish and algal cultures. While potential disturbance of such activities by petroleum exploration activity to date is not readily evident, future disturbance could readily be avoided. Other significant biological elements such as dugongs, the Irrawaddy River dolphin and turtles may be present in areas of the coastal zone where future exploration activity could be located.

Potential effects

Seismic

The initial form of exploration activity likely to occur in any potential release area comprises seismic surveying work. This activity generally is undertaken by the towing of surveying equipment, in the form of a receiver cable and acoustic signal source, along a grid of survey lines sufficient to determine the subsurface geological structure of the region. As the activity is brief and coverage of the region is generally sparse, limited if any environmental effect occurs. The impact of the periodic acoustic signal on fish and invertebrate populations is minimal unless they are within a metre or so of the signal source (Neff & others, 1987). Some concerns have been raised about the disturbance effects of such signals on larger marine mammals at close range (less than 1 km) even though the noise from a seismic source is less than that generated by mammals during periods of vigorous activity.

Noise appears to be the only factor causing any disturbance to normal marine habitats as a result of petroleum industry activity. Under most circumstances, according to Geraci & St. Aubin (1987) marine mammals and vertebrates habituate to low level background noise. The most significant disturbance effects have occurred around the world where such activities are of part of a widespread disturbance of the environment, resulting in subtle changes in environment and habitat (Geraci & St. Aubin, 1987).

Drilling

Exploration drilling involves drilling of a subsurface bore into geological sequences which may contain natural accumulations of petroleum. As it is undertaken using purpose-designed vessels their anchoring and limited operation provide no long-term impact and only limited local disturbance within a small area. Less than 40 days of operation are generally involved in the drilling of exploration wells and the main initial activity involves the installation of subsurface tubing and associated cementation.

Excavation of the well bore generates cuttings of subsurface rock which are size-sorted and washed prior to discharge to the sea bed where ultimate dispersal by local currents readily occurs. Drilling fluids used to lubricate drill bits, maintain and clean out the well bore generally comprise a mixture of sea water and naturally-occurring clay minerals. Limited amounts of the clay mineral component may be present on the rock cuttings discharged to the sea bed. Limited quantities of fluids such as treated sanitary wastes are also discharged to the sea during such operations, as would take place during any normal maritime operation.

Production

Should the results of exploratory drilling warrant it, fixed or floating structures could be installed to commercially develop any potential hydrocarbon accumulation(s). Development for such accumulations could involve drilling of a number of development wells from drilling/production facilities. Production will usually, in the case of crude oil production, involve the discharge of subsurface water separated from the crude oil into the sea after processing. If full processing is undertaken onboard the offshore facility offloading and transportation are required, otherwise a pipeline connection to shore-based facilities will be installed. The functioning and effects of such operations are beyond the scope of this analysis and the most relevant local guide to the long term effects of such operations are production platforms and facilities of the Gippsland Basin in Bass Strait.

Major studies of the ecological impact of production facilities are available for a range of marine habitats. Some ecological changes do occur and these are largely related to artificial reef effects or changes due to the presence on the sea bottom of cuttings. Other changes are subtle and not readily detectable without great sampling effort (Spies, 1987).

Conclusions

The baseline data for environmental conditions in the Timor Sea, including the vacant area in the East Malita Graben area, can be assessed from the BMR study undertaken by van Andel & Veevers (1967). The pattern of lithofacies, biofacies and oceanographic data from the region collected in 1960-61 before the first seismic (1963+) and drilling (petroleum exploration) activities were undertaken in region (1969-70) provides a useful reference frame with which any post-exploration patterns can be compared.

From available data it is evident that the transitory nature of exploration operations are such that minimal localised disturbance can be expected from seismic and drilling activities. Cuttings generated during drilling operations are the only significant traces of such work and these are rapidly reworked and removed by normal marine processes.

No visible long term effects are anticipated from such activities if the work record of the industry attained elsewhere in Australian is maintained by future work in this region.

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